Device to generate a three-dimensional image of a moved object

The invention relates to a method and a device for generating a three-dimensional image of an object e.g. the heart, which is subject to cyclic movement.

US 2002/0126794 A1 discloses a rotation X-ray device with which three-dimensional images of a patient's heart can be reconstructed. One problem with such reconstructions is that the object to be shown is not static but because of the heart beat is subject to a cyclic movement. Another important source for the movement of organs in medical examinations is the respiration of a patient. The 2D projections of the heart taken with a rotation X-ray device from various directions show the heart in different movement states. If these projection images are used to reconstruct a 3D image of the heart on the assumption that they reflect a static object, reconstruction errors necessarily occur. To minimize such errors US 2002/0126794 A1 proposes recording the electrocardiogram (ECG) in parallel to the X-rays and then using for reconstruction of the three-dimensional image only those X-ray pictures which correspond to approximately the same ECG phase. With such a method oriented to the ECG phase a substantial improvement in the 3D reconstruction can be achieved. Nonetheless it appears that furthermore certain inaccuracies and artifacts can occur in the reconstructed image.

In this context one object of the invention is to provide means for generating three-dimensional images of a cyclically moved object such as in particular the heart, which give improved image quality.

This object is achieved by a device with the features of claim 1 and by a method with the features of claim 8. Advantageous embodiments are contained in the sub-claims.

The device according to the invention serves to generate a three-dimensional image of an object which is subject to a cyclic movement. The object can in particular be a patient's heart, where the invention is not however restricted to medical applications. The device contains an imaging device with which two-dimensional projection images of said object can be generated from different projection directions. The device furthermore contains

a data processing device coupled with said imaging device which is designed, for example by fitting with corresponding software, to reconstruct from the projection images a three-dimensional image of the object. Processes and algorithms suitable for this task are for example known from the field of computer tomography. The data processing device is furthermore designed to select and use for said reconstruction of the three-dimensional image only those projection pictures for which the projection lines of a characteristic object feature intersect approximately at the same spatial point. A "characteristic object feature" is a feature which is attached to the object and follows its movements, identifies a body point and which can be shown as well as possible on the projection pictures. The object feature can for example be a marker on the object which stands out well on the projection pictures. "Markers" in this respect can e.g. also be a catheter or a stent (vessel connector). Similarly the object feature can be part of the object, for example a branch point of an object structure. In the context of medical applications in particular the branch point of a vessel can serve as an object feature. Furthermore the "projection line" of an object feature is the (imaginary) spatial line which for a given projection picture leads from the projection center through the object feature to the image point of the object feature on the projection plane or projection picture. In an X-ray image the projection line e.g. corresponds to the path of the X-ray beam from the beam source through the object feature to the associated pixel on the detector. Furthermore for the "approximate intersection" of projection lines (which evidently must include a precise intersection), depending on the peripheral conditions concerned, a suitable decision limit must be established in individual cases. For example all such projection lines can be regarded as intersecting approximately at the same spatial point if they draw closer together than 1% to 5% of the maximum width of the projection picture. Similar standards can evidently also be defined using other reference values such as for example the object size.

Using the device described it is possible to create three-dimensional images of a moved object in high quality, as for reconstruction of the 3D image only those two-dimensional projection pictures are used which already match well at the point of (at least) one characteristic object feature. It is therefore to be assumed that these projection pictures also correspond in the other object points or that for the selected projection pictures the object was in the same phase of cyclic movement and therefore had assumed approximately the same spatial position. When the device is used to show the heart, in contrast to the known processes based on the electrocardiogram, the advantage appears that the movement state of the heart is used directly as a selection criterion. The selection of projection pictures from the

same ECG phase however is based implicitly on the assumption that the movement phase of the heart cycle is also clearly linked to the electrical phase. This assumption is however not always fulfilled precisely so that with the known ECG-based processes, reconstruction errors can occur. These errors are in principle excluded with the device proposed here.

Said condition for the selection of projection pictures for reconstruction of a three-dimensional image can evidently also be imposed similarly for more than one object feature. The selection method can thus e.g. be performed iteratively with one object feature after the other where the selection of projection pictures produced on each iteration is used as the basis for the next iteration, so the selection becomes ever narrower. In this case the precision increases as the position of the object in the selected projection pictures already matches at a corresponding number of points.

For the imaging part of the device in principle any device can be used with which projection pictures of an object can be generated from different directions, from which pictures a three-dimensional image can be reconstructed. Examples of these are an ultrasound device or an NMR device. In particular the imaging device can also be an X-ray device with an X-ray source and an X-ray detector which are rotatably mounted about a common axis. X-ray machines of this type are known from 3D rotation angiography (3D-RA) and the X-ray source and detector are typically attached to a C-arm.

Furthermore the device preferably comprises a display device coupled with a data processing system such as for example a monitor on which the reconstructed three-dimensional image can be shown. Such a display device allows for example a doctor to display visually the results of the three-dimensional reconstruction and analyze this directly for his diagnostic or therapeutic activities.

According to a preferred embodiment of the device the data processing machine is set up to perform the following steps:

a) selection of a first projection picture from a number of several projection pictures from different projection directions. This selection of the first projection picture can be arbitrary (e.g. on a random principle), interactive by a user or from other application-specific criteria (e.g. the imaging quality or associated ECG phase).

b) for the first said projection picture, a second projection picture taken from another projection direction is selected such that the projection lines of a characteristic object feature for the first and second projection picture intersect at least approximately at a spatial point. The characteristic object feature can in particular be located by a method of automatic image processing or interactively by a user and should be such that it can be detected in as

many projection pictures as possible. After locating the characteristic object feature on a particular projection picture, the spatial projection line is calculated from the projection center to the image point of the object feature so that it can be checked whether it intersects approximately the corresponding projection line of the first projection picture. If this is the case the projection picture concerned is selected as the "second projection picture". The intersection point of the projection lines thus establish the spatial point which corresponds to the (presumed) actual position of the object feature and which is used for the subsequent selection of further projection pictures.

c) further projection pictures for reconstruction of the three-dimensional image are selected such that the associated projection lines of the object feature used in step b) run approximately through the spatial point determined in step b). In total thus successively a sub-quantity of projection pictures is selected from the given number of projection pictures which match each other in relation to the spatial position of the characteristic object feature concerned.

With the embodiment of the invention described above, the projection direction of the second projection picture preferably lies at an angle of around 90° to the projection direction of the first projection picture. In particular it can lie in an angular range between 70° and 110° to the first projection direction. In this way the spatial point which is later used for the selection of all projection pictures used for reconstruction can be established with maximum precision. Based on the first projection picture, of this spatial point namely only two of its three degrees of freedom are established as its position along the projection line of the first projection picture cannot be determined. The third degree of freedom is determined by the intersection of the projection lines of the second projection picture with the projection line of the first projection picture. In the case of a second projection picture essentially perpendicular to the first projection picture, any error in determining the position of the object feature in the projection is carried forward to a minimum in the determination of the spatial point.

The invention further relates to a method for producing a three-dimensional image of an object which is subject to a cyclic movement. The method comprises the following steps:

a) generation of a number of projection pictures of the object from various spatial directions;

b) selection of projection pictures for which the projection lines of a characteristic object feature intersect approximately at the same spatial point;

c) reconstruction of the three-dimensional image from the projection pictures selected in step b).

The method in general comprises the steps which can be executed with a device of the type defined above. For the further explanation of the method and its advantages therefore reference is made to the above description of the device. In particular the method can be refined according to the features of the variants of the device and for example comprise the steps which can be executed with the data processing device as claimed in claim 6.

In an optional embodiment of the method the projection pictures are generated by X-ray projection of the object, where the respective projection centers from which the X-ray beam is emitted are distributed approximately on a circle arc about the object. Typically the circle arc extends over a range of about 180° in order to cover all independent projection directions.

Furthermore the three-dimensional image reconstructed according to the method is preferably shown on a display device to be able to be analyzed visually by the user.

The invention will be further described with reference to examples of embodiments shown in the drawings to which however the invention is not restricted. These show:

Fig. 1 diagrammatically the structure of a device according to the invention to generate a three-dimensional image of the heart,

Fig. 2 a principle view of the conditions in the selection according to the invention of two-dimensional projection pictures of the same movement state of the heart,

Fig. 3 the size of the euclidean interval Δ_n between the projection of a spatial point $\underline{r}_0$ which corresponds to the spatial position of the object feature in a particular heart phase, and the position of the image point of this object feature on a viewed projection picture with index n.

The invention will be explained below without restriction of generality using the example of a medical application, namely the three-dimensional imaging of the heart or the coronary vessels of a patient. The device used for this according to Fig. 1 as an example device comprises a rotation X-ray apparatus 1 with an X-ray source 2 and an X-ray detector

5. The X-ray source 2 and the X-ray detector 5 are arranged opposite each other on a C-arm 6 and can be swiveled about the patient 3 lying on a couch 4 (two swiveled positions as shown in dotted lines in the figure). The X-ray projection pictures P_{i-1}, P_i, P_{i+1},.... of the heart generated from various projection directions are transmitted to a data processing device 7 (e.g. a work station) used for control and image processing. The data processing device 7 comprises in particular software with image processing algorithms with which from the two-dimensional projection pictures P_{i-1} , P_i, P_{i+1},...., the three-dimensional form of the object or its structures for example coronary vessels, can be reconstructed. The corresponding algorithms are known from computer tomography and therefore need not be explained in more detail here. The result of the three-dimensional reconstruction can be shown on a monitor 8 coupled to a data processing device 7 in order to give the treating doctor an overview image of the vascular tree.

In said reconstruction for a three-dimensional image of the coronary vessels, it must be noted that because of the heart beat, the heart is subject to a cyclic movement. The projection pictures P_{i-1} , P_i, P_{i+1},.... produced therefore stem from different phases T_1, T_2, T_3 of the cardiac cycle during which the heart assumes different spatial positions. For the reconstruction only those two-dimensional projection pictures (e.g. P_{i-1} , P_{i+1}) should be used which correspond to the same cardiac movement phase (e.g. T_2 which can be the end of a diastole). In known methods the corresponding selection of projection pictures takes place on the basis of a parallel recorded electrocardiogram. The ECG however primarily represents the electrical state of the cardiac cycle, which does not always correlate to the movement state. In known methods the reconstructed 3D image thus often has a residual inaccuracy.

To avoid the outlined problems, primarily the method explained in more detail below with reference to Fig. 2 is proposed for the selection of projection pictures for the reconstruction of a 3D image. Fig. 2 shows in a perspective principle view the geometric conditions in the taking of projection pictures P_i, P_j, P_k, P_l,.... Each of the projection pictures arises as a central projection of an object starting from a projection center S_i, S_j, S_k, S_l,.... The project centers correspond to the position of the X-ray source 2 during the projection picture concerned and are distributed on a curve (e.g. circle arc) which in the optimum case covers an angle of more than 210°. The radiographed object 9 is shown in the center for the time of projection picture P_i where it must be pointed out that during the other projection pictures it usually has a different form and position. The vascular branch contained in the object 9 constitutes a suitable object feature as it marks a point on the object 9 which in (almost) all projection pictures can be located relatively well. Instead of a vascular branch a

marker can be used as an object feature such as for example a position marker impervious to X-rays on a catheter.

At production of the projection picture P_i the object feature which is the branch of object 9 lies at a spatial point $\underline{r}_0$ which is initially unknown. This spatial point $\underline{r}_0$ is shown starting from the projection center S_i via the projection line l_i in the image point X_i of the object feature on the projection picture P_i. The position of the image point X_i in the projection picture P_i can be located interactively or automatically using known methods of image processing. Similarly the position of the image point of the object feature on the other projection pictures can be determined (e.g. the image points X_j, X_k in projection pictures P_j or P_k) which were taken from other projection directions and usually belong to other phases of the cardiac cycle.

From the projection pictures a first projection picture P_i is now selected at random by interaction of a user or otherwise. Starting from this all further projection pictures are determined which were taken in a similar movement phase of the heart as the first projection picture P_i. To this end first a second projection picture is selected. According to a first criterion its projection direction should lie approximately at an angle α of 90° to the projection direction of the first projection picture P_i. In the view in Fig. 2 thus the projection pictures about P_k are primarily concerned. For these projection pictures P_k,.... then according to a second criterion it is examined whether the associated projection lines l_k,.... intersect the projection line l_i of the first projection picture P_i or come closer to this than the prespecified maximum distance. In Fig. 2 this is the case for projection line l_k which connects the projection center S_k with the image point X_k of the object feature on the projection picture P_k. The projection picture P_k thus determined is then established as the "second projection picture" and the (approximate) intersection of projection lines l_i and l_k defines, for the further process, the spatial point $\underline{r}_0$ at which the object feature (vessel branch) was presumably located during the basic cardiac movement phase.

The selection explained above of the second projection picture P_k can be performed in an equivalent manner using epipolar lines. For the projection picture P_k the epipolar line $E_k(i)$ is drawn in dotted lines. It corresponds to the theoretical projection of the projection line l_i taken from the projection center S_k and therefore describes all theoretically possible locations of the object feature from knowledge of only the first projection picture P_i. The latter mainly establishes the spatial position of the object feature only to one degree of freedom, as it cannot be decided from the projection picture P_i where on the projection line l_i the object feature lies. Using the epipolar lines now for every other projection picture the

euclidean interval can be calculated of the image point X_k,.... located on the respective projection picture P_k,.... of the object feature from the corresponding epipolar line $E_k(i)$. The second projection picture P_k to be selected is distinguished in that its object feature image point X_k has the smallest distance from the associated epipolar line $E_k(i)$.

Using the first and the second projection pictures P_i and P_k as stated, the spatial point $\underline{r}_0$ of the position of the object feature during the cardiac phase concerned can be determined. Thus this spatial point $\underline{r}_0$ can be projected theoretically onto any other projection pictures. For example for projection picture P_j point X'_j is calculated at which the spatial point $\underline{r}_0$ is projected from projection center S_j. The euclidean distance Δ_j between this projection point X'_j and the image point X_j of the object feature in the projection picture P_j constitutes a measure of how greatly the cardiac movement phase in which projection picture P_j is taken deviates from the cardiac movement phase during the first and second projection pictures P_i, P_k. For the desired reconstruction of a three-dimensional image thus in a targeted manner those projection pictures P_l can be selected for which said distance is nil or lies below a prespecified threshold.

With said method thus from the series of projection pictures P_i, P_j, P_k, P_l, ... those can be selected which belong to the same cardiac movement phase, wherein advantageously true movement data and not derived electrical activities are used to determine the cardiac cycle. It is furthermore advantageous that the object feature used can be selected from a particularly interesting region of the object 9 and this region as priority is represented with high precision in the three-dimensional image.

Fig. 3 shows, for the projection pictures arranged according to the projection direction and numbered with index n (horizontal axis), the respective size of the euclidean distance Δ_n defined above between the calculated projection of the spatial point $\underline{r}_0$ and the respective image position of the object feature. The cyclic variation corresponding to the cardiac rhythm is clear. For reconstruction of the three-dimensional image according to the above method, only the projection pictures from the "valleys" of the curve are used.